



# Observation of the Dependence of Scintillation from Nuclear Recoils in Liquid Argon on Drift Field

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On Behalf of SCENE Collaboration (Scintillation and Ionization Efficiency of Noble Elements)

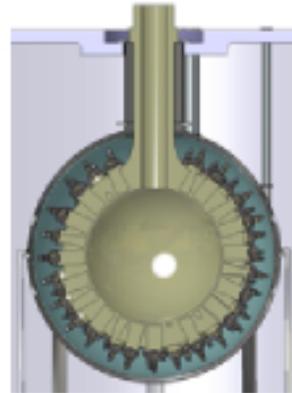
Member Institutions:



# Liquid Argon (LAr) as WIMP Target

Scintillation / S1: Excellent pulse shape discrimination (PSD) of nuclear (NR) versus electron recoils (ER)

Single-phase  
S1 only



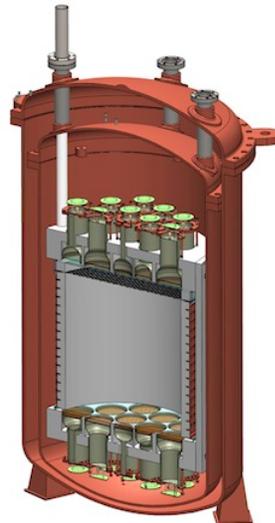
DEAP  
SNOLAB



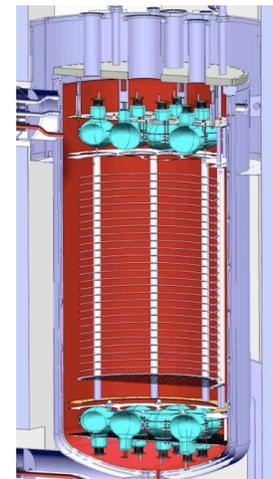
CLEAN  
SNOLAB

Ionization / S2: enables position reconstruction and additional ER discrimination

Dual-phase  
S1+S2



DarkSide  
Gran Sasso



ArDM  
Canfranc

# Scintillation and Ionization Yield for Nuclear Recoils (NR)

- Knowledge of those quantities is required to convert a NR signal to the deposited energy
- They decide the energy threshold of LAr detectors and inferred WIMP mass

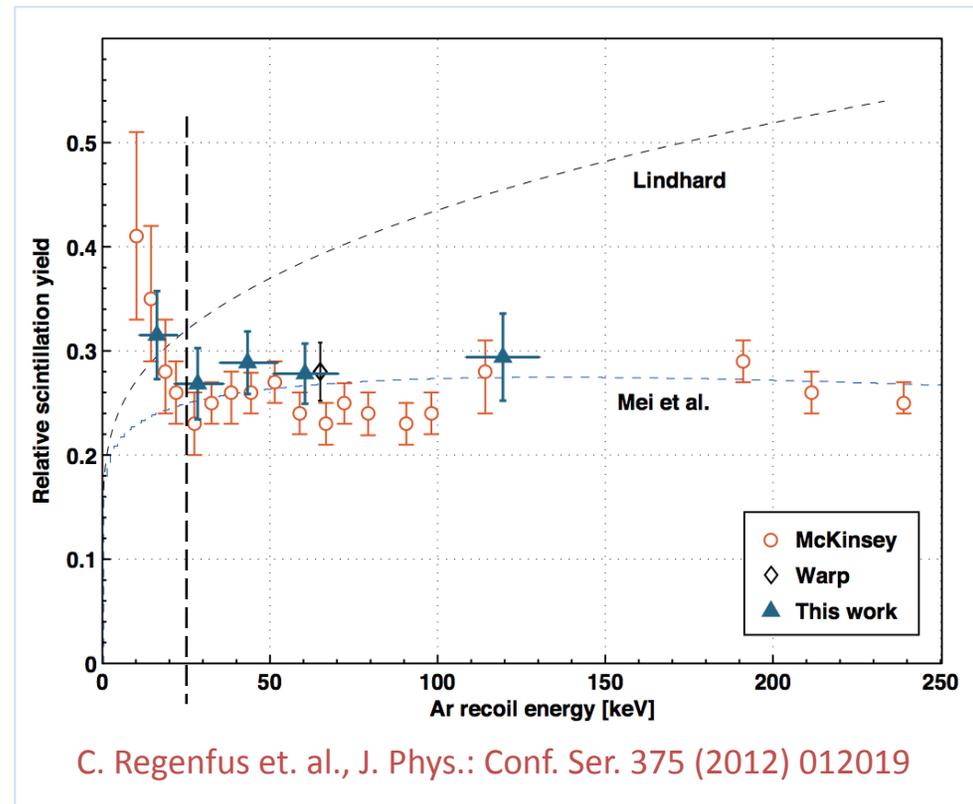
Scintillation:

Yield for low energy ( $<25 \text{ keV}_r$ ) NR has not been precisely determined in the literature

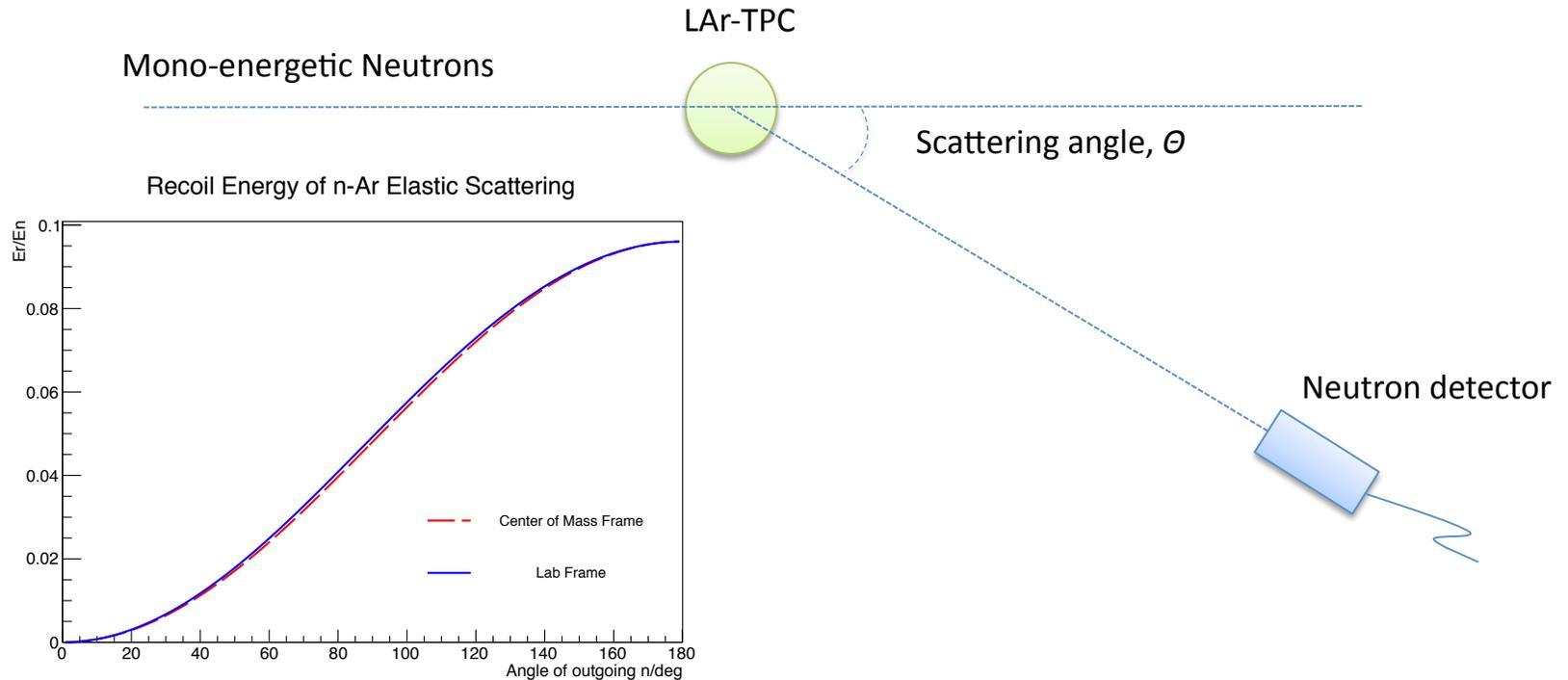
Effects of applied electric field (both on PSD and scintillation yield) need to be characterized for two-phase Ar time projection chamber (LAr-TPC)

Ionization:

No comprehensive measurement of the ionization yield has been published



# Nuclear Recoils from Elastic Scattering of Neutrons



## The Challenges

1. Compact LAr detector to minimize multiple scatterings
2. Unambiguously select NRs of a known energy

# LAr-TPC

Active LAr volume: 76 mm x 69 mm dia.

Inactive LAr volume: 15 mm, annular

Hamamatsu 3" PMT R11065 (QE 420nm: 33%)

Reflector: 3M Vikuiti

Wavelength shifter: 200  $\mu\text{g}/\text{cm}^2$  1,1,4,4-Tetraphenyl-1,3-butadiene (TPB) on reflector and windows

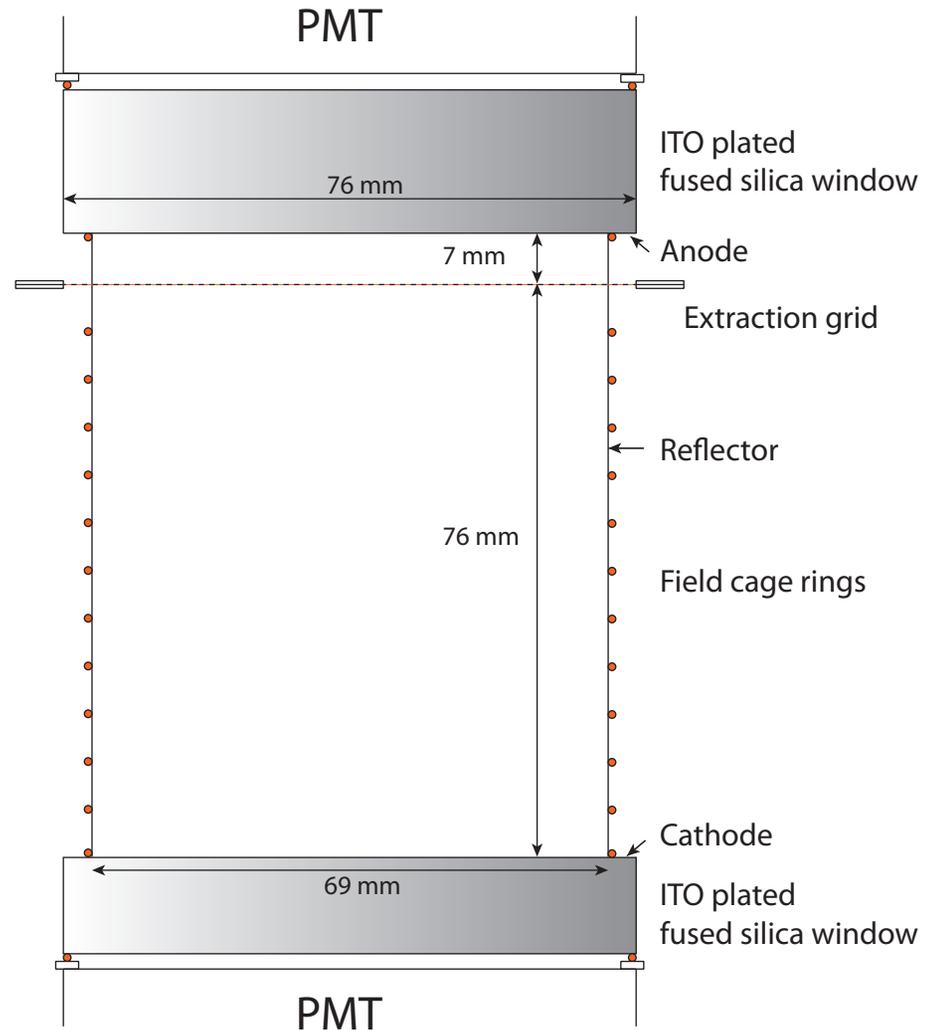
Electrodes: 20 nm Indium Tin Oxide (ITO) on fused silica windows

Max anode voltage tested: +4.5 kV

Max cathode voltage tested: -8.0 kV

Grid: SS hexagonal mesh, GND

Drift field and extraction field can be set independently



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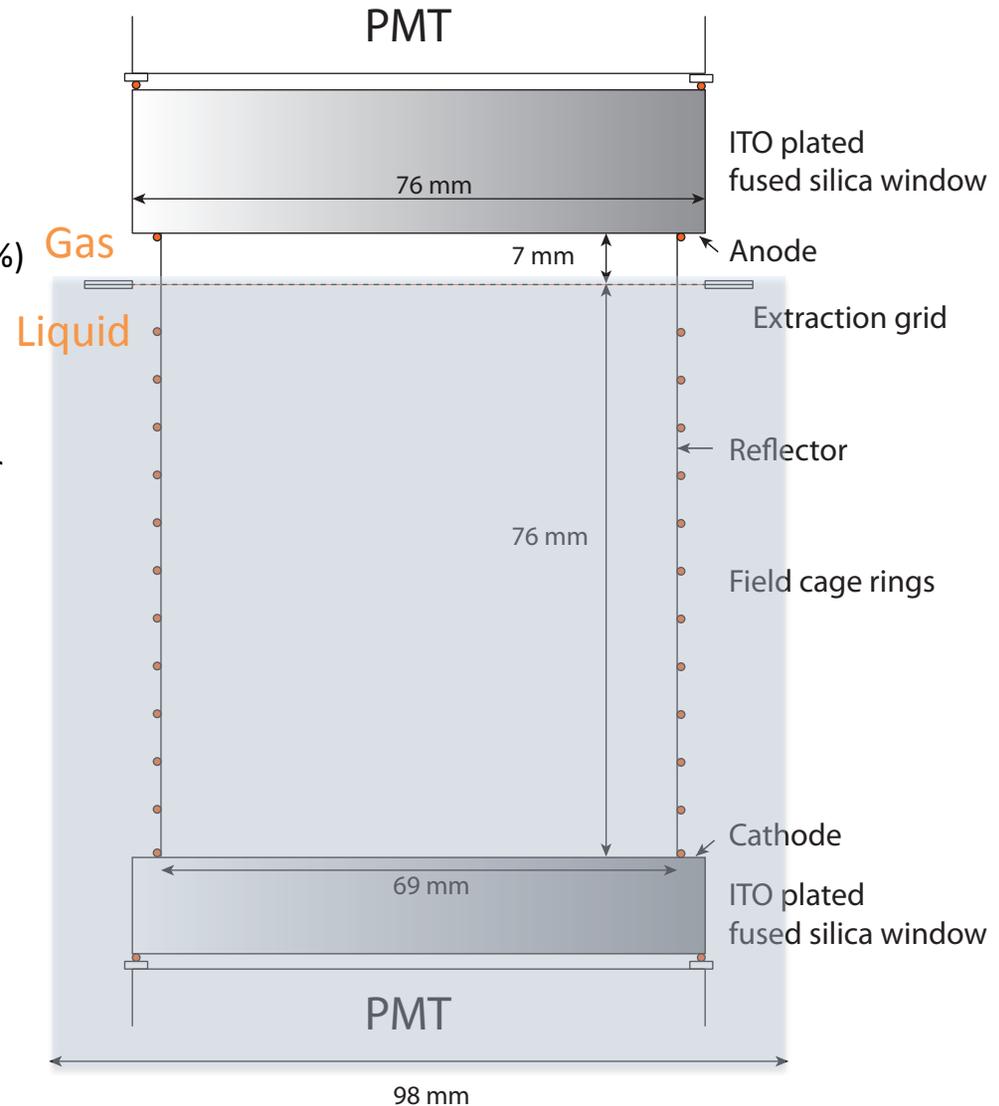
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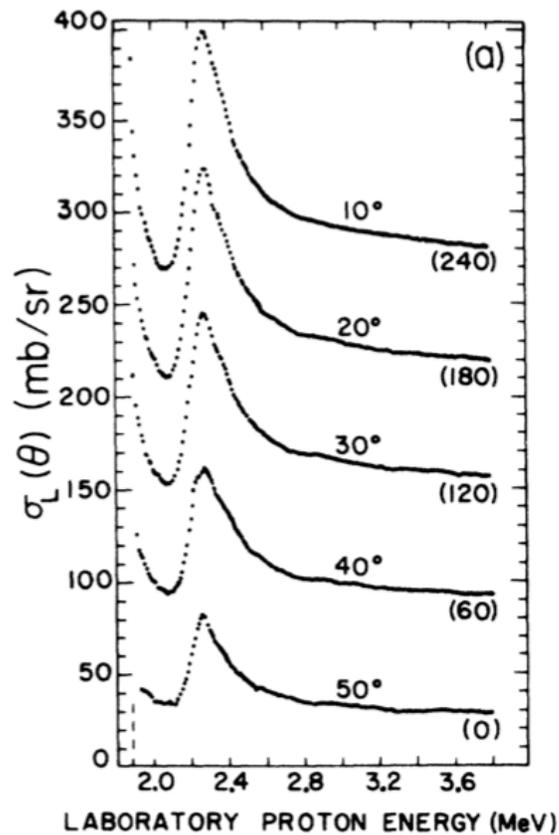
Drift field and extraction field can be set independently



# ${}^7\text{Li}(p, n){}^7\text{Be}$ Reaction

Ref: C.A.Burke et al., Phys. Rev. C 10, 1299 (1974)

Generate neutrons with  $E_n$  on the order of MeV with precise energy and high flux



Vertical offset in ( ) to be subtracted

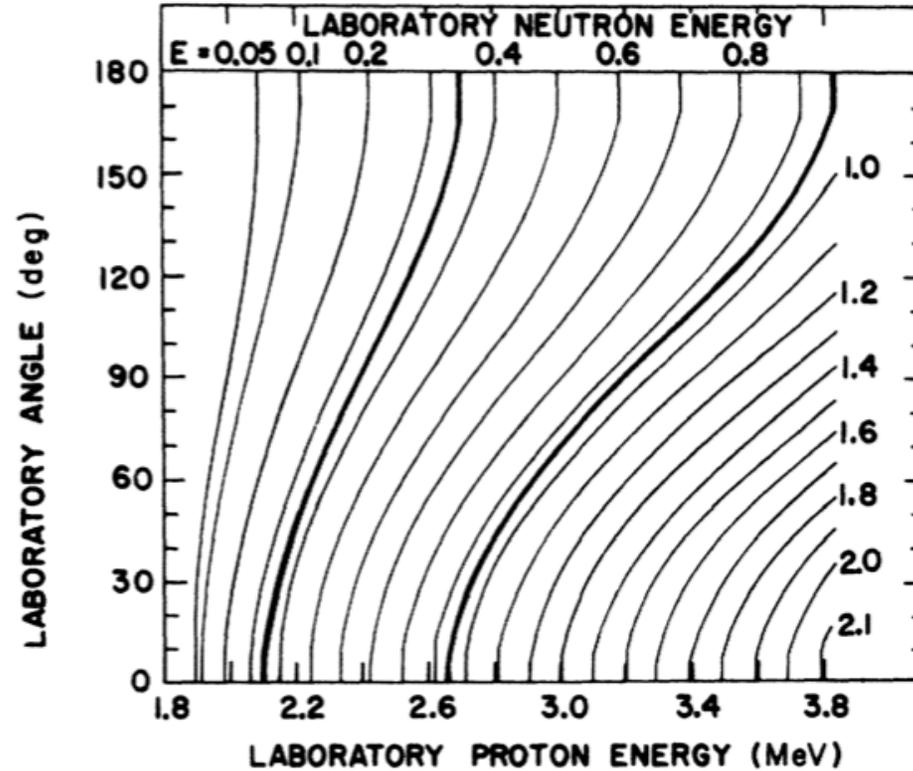
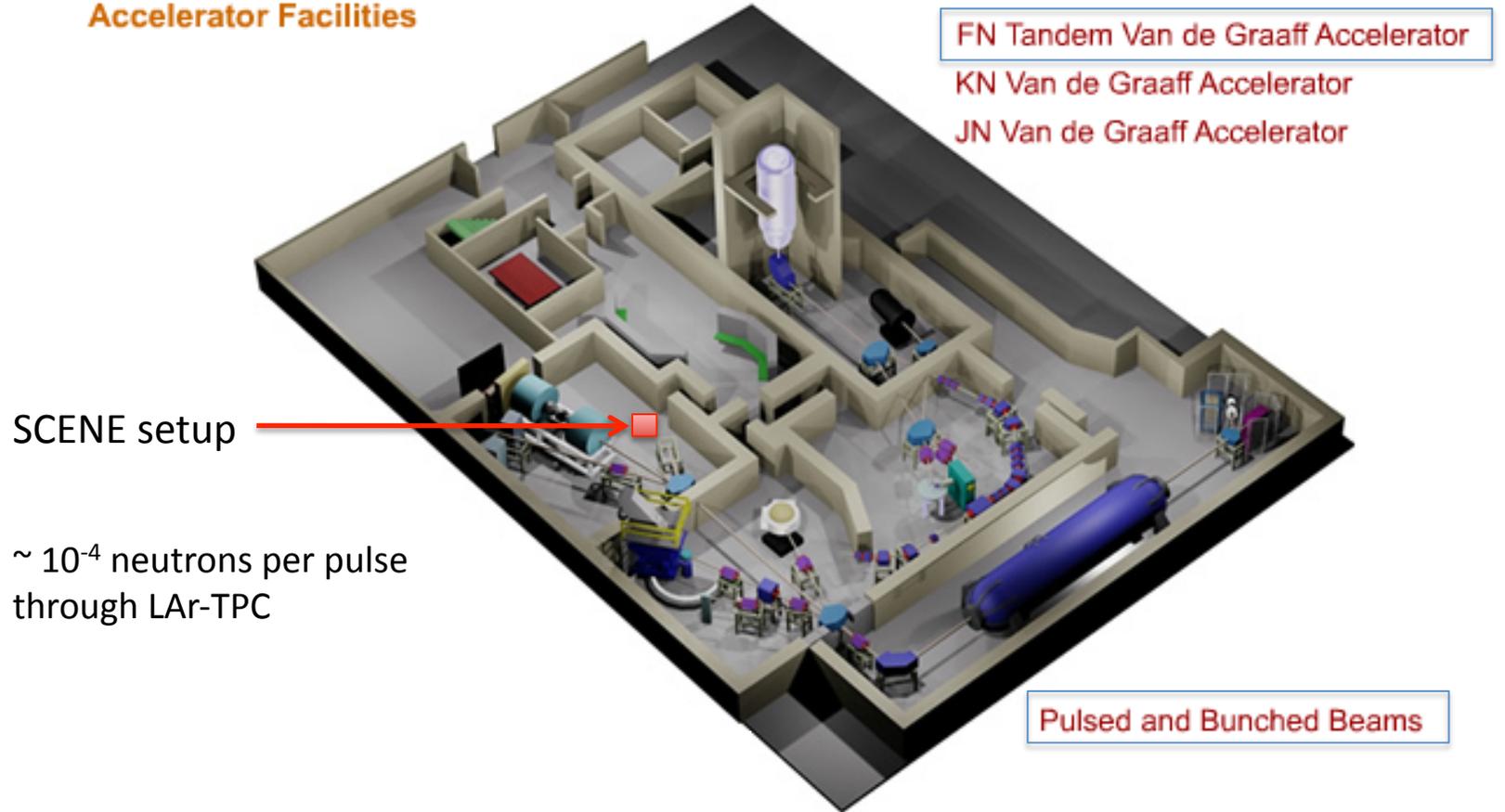


FIG. 4. Traces of constant laboratory neutron energy versus laboratory proton energy and reaction angle for  ${}^7\text{Li}(p, n){}^7\text{Be}$ . The wide lines delimit the neutron energies for which complete angular distributions were obtained.

# Proton Beam at University of Notre Dame

## Accelerator Facilities

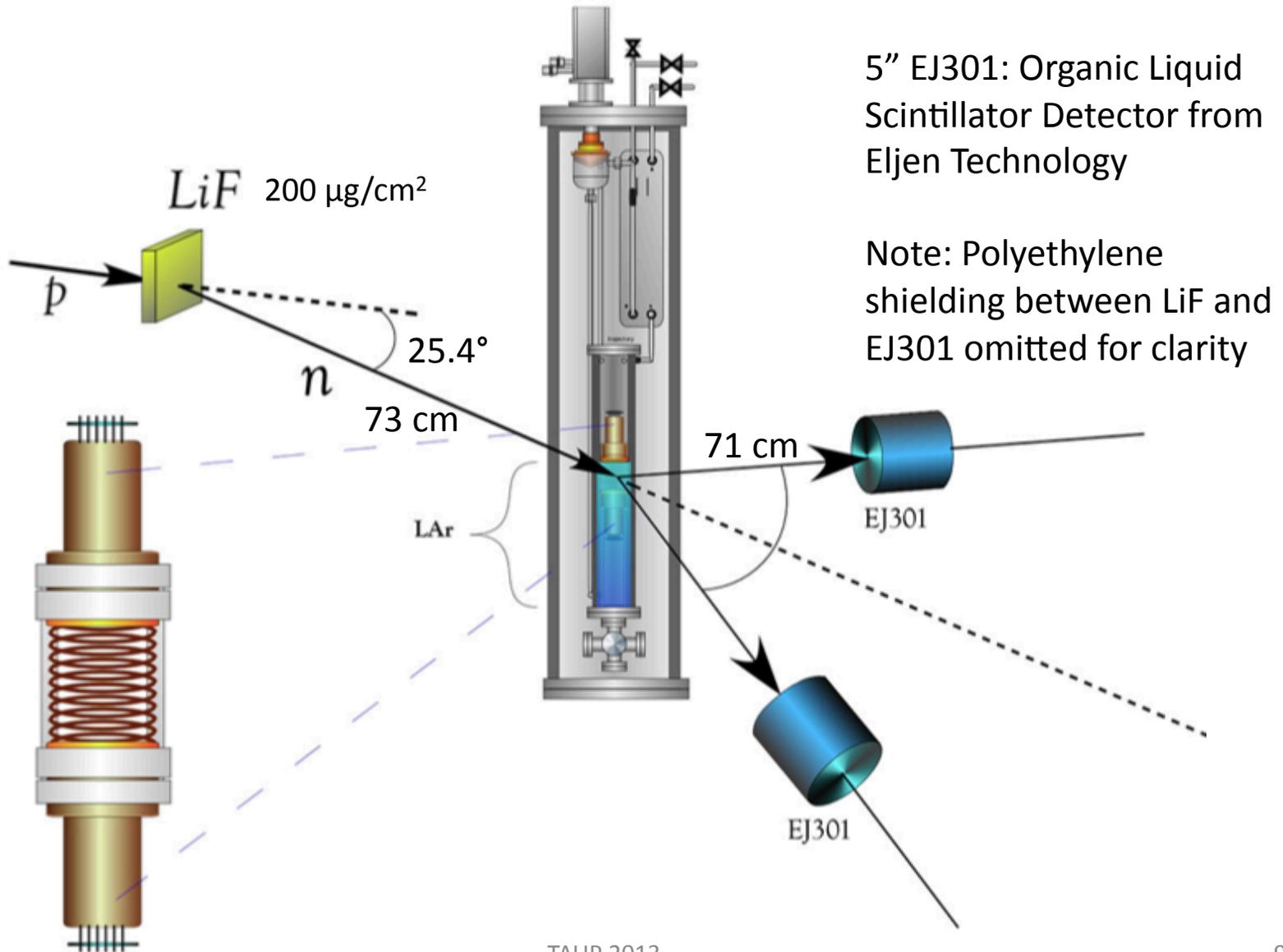


$\sim 10^{-4}$  neutrons per pulse  
through LAr-TPC

- period = 101.5 ns or its multiples  
used 203 ns
- max current = 300 nA  
used  $\sim 50$  nA

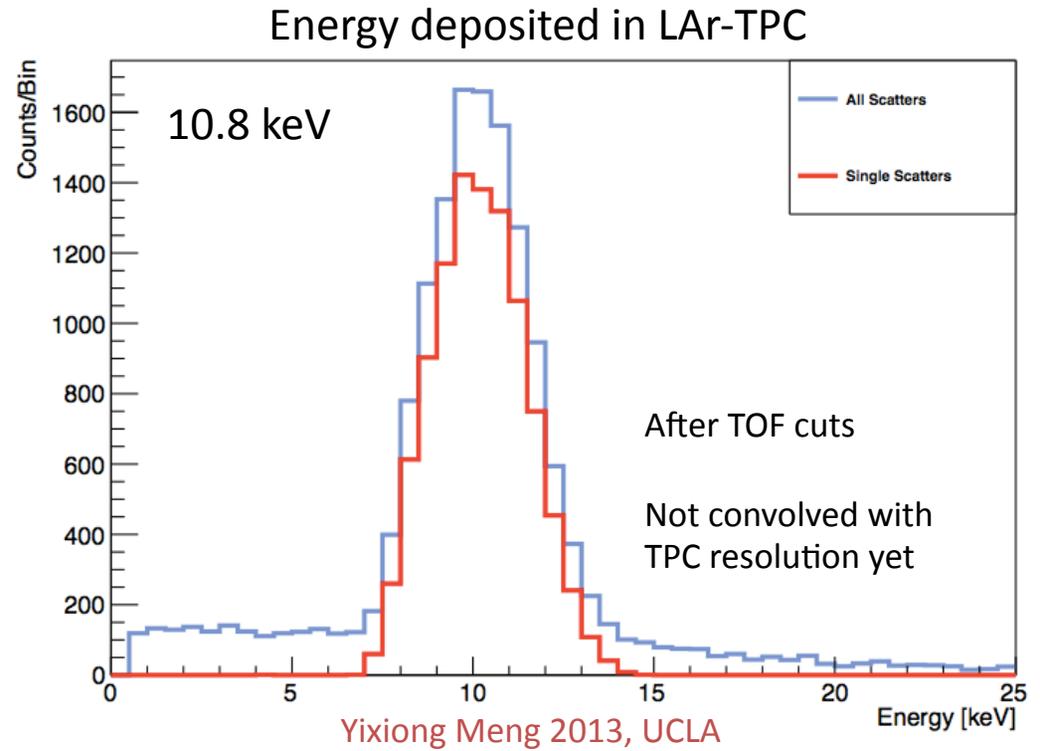
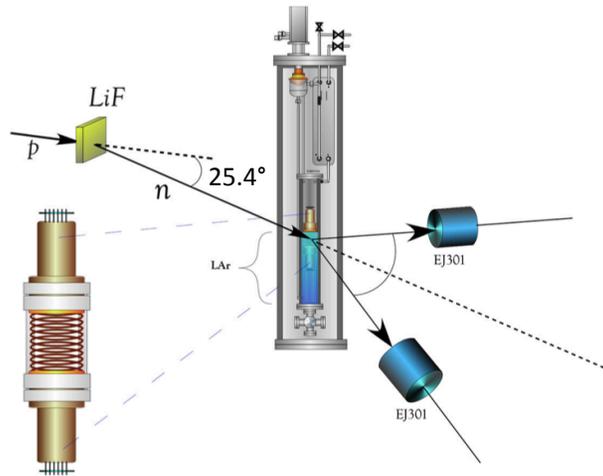
- beam angle spread at target  $< 0.006$  deg
- $\pm 1$  keV mean uncertainty
- $\pm 2$  keV spread
- 10 MeV maximum

# Experimental Layout



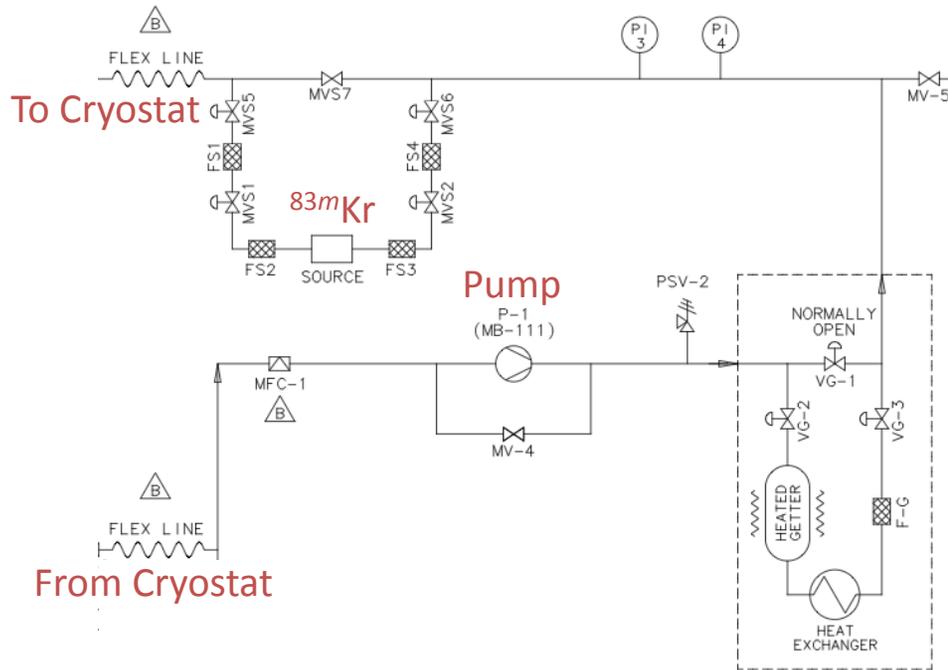
# Geant4 Monte Carlo Simulation

Proton energy (MeV)	Neutron energy (MeV)	Scattering angle (°)	Nuclear recoil energy (keVr)
2.376	0.604	49.9	10.8
2.930	1.168	42.2	15.2
2.930	1.168	49.9	20.8
2.930	1.168	59.9	29.0
2.930	1.168	82.2	49.9



- Simulation started with a realistic neutron distribution from  ${}^7\text{Li}(p, n){}^7\text{Be}$  reaction
- Included detailed features of the TPC and cryostat
- The position of the single scattering peak is not affected by the background
- Multiple scattering contributes less than 23% of the total rate between 5 and 16 keV

# $^{83m}\text{Kr}$ Source as Light Yield Monitor



Continuous recirculation during the beam run for maintaining  $^{83m}\text{Kr}$  activity (1.2 kBq) and LAr purity

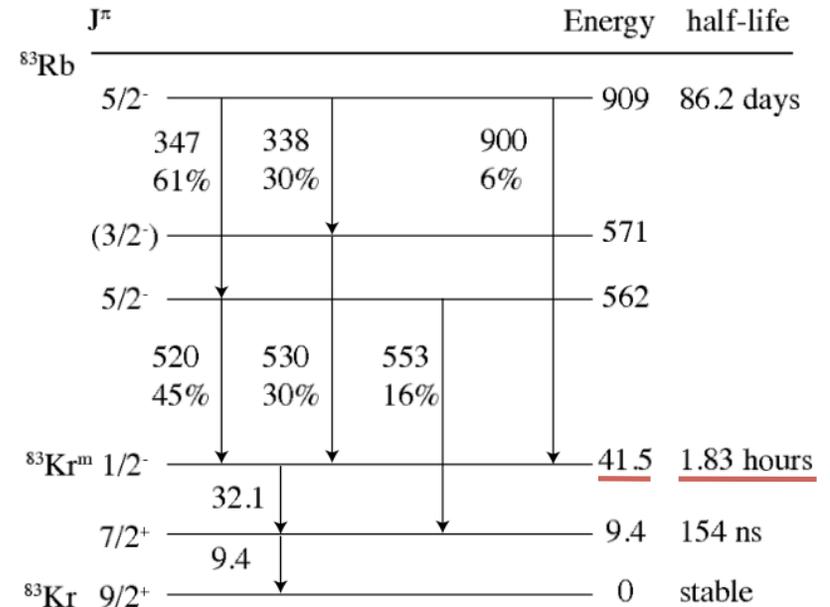
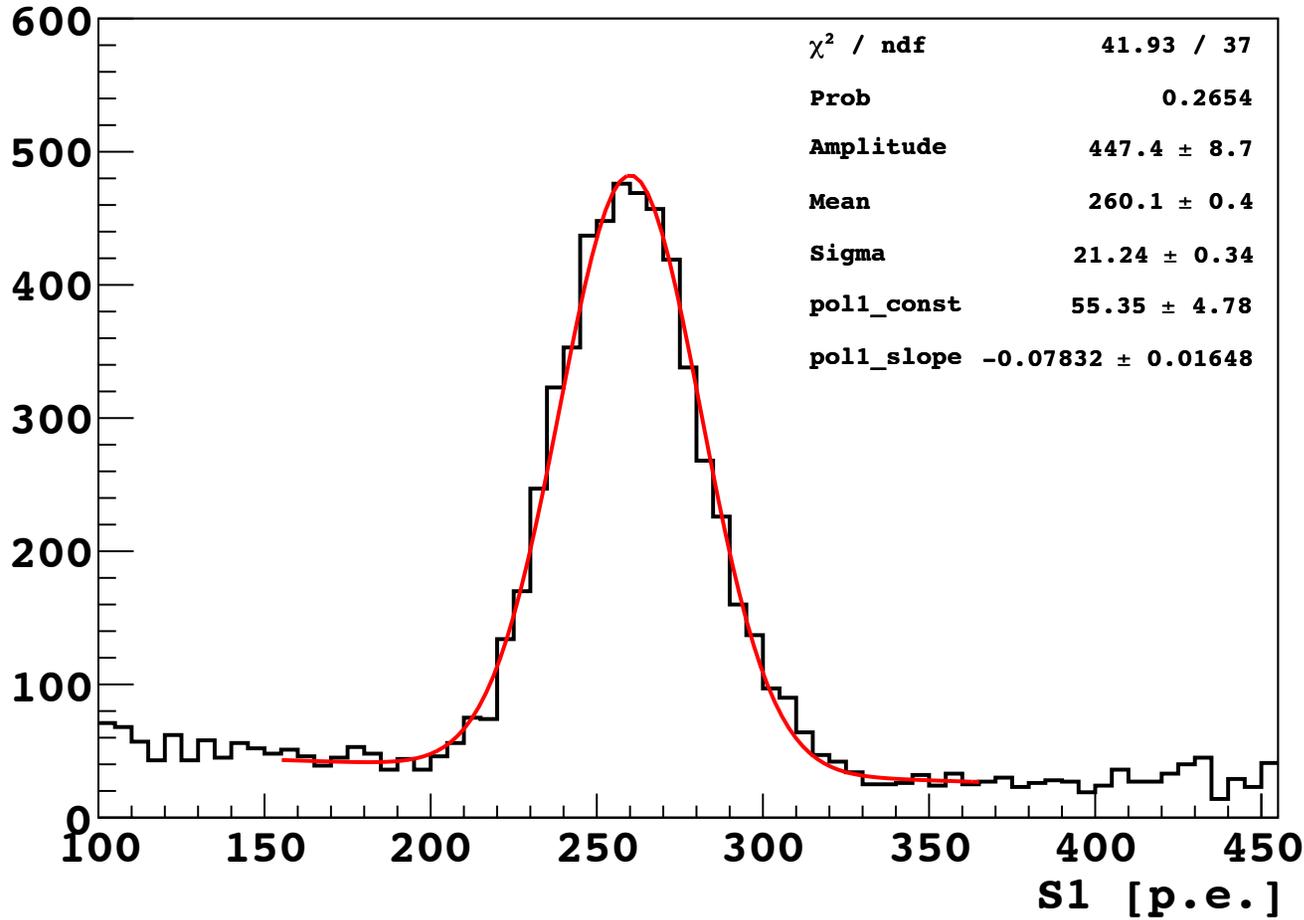


FIG. 1. Energy levels in keV of  $^{83}\text{Rb}$ . For 75% of the time,  $^{83}\text{Rb}$  decays to  $^{83}\text{Kr}^m$ , which in turn decays via electromagnetic transitions with energies of 32.1 and 9.4 keV. The half-life of  $^{83}\text{Kr}^m$  to decay via the first transition to the 7/2<sup>+</sup> state is 1.83 h and the half-life for the subsequent decay to the stable 9/2<sup>+</sup> state of  $^{83}\text{Kr}$  is 154 ns.

Lippincott et al., Phys. Rev. C 81, 045803 (2010)

# $^{83m}\text{Kr}$ Source as Light Yield Monitor

## $^{83m}\text{Kr}$ Source



half-life  
86.2 days

1.83 hours

154 ns  
stable

of the time,  $^{83}\text{Rb}$   
beta transitions  
 $^{83m}\text{Kr}$  to decay  
the half-life for  
is 154 ns.

(2010)

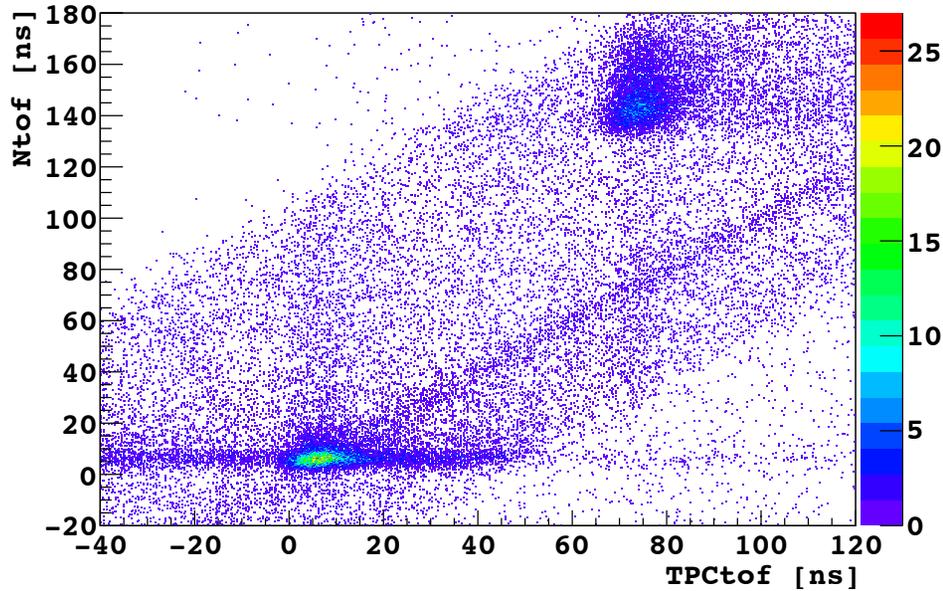
  
To Cryostat

  
From Cryc

Cont  
bear  
activ

Variation of  $^{83m}\text{Kr}$  peak mean within 2.4% over all data

# Data (10.8 keV, $E_{\text{drift}} = 1000 \text{ V/cm}$ )



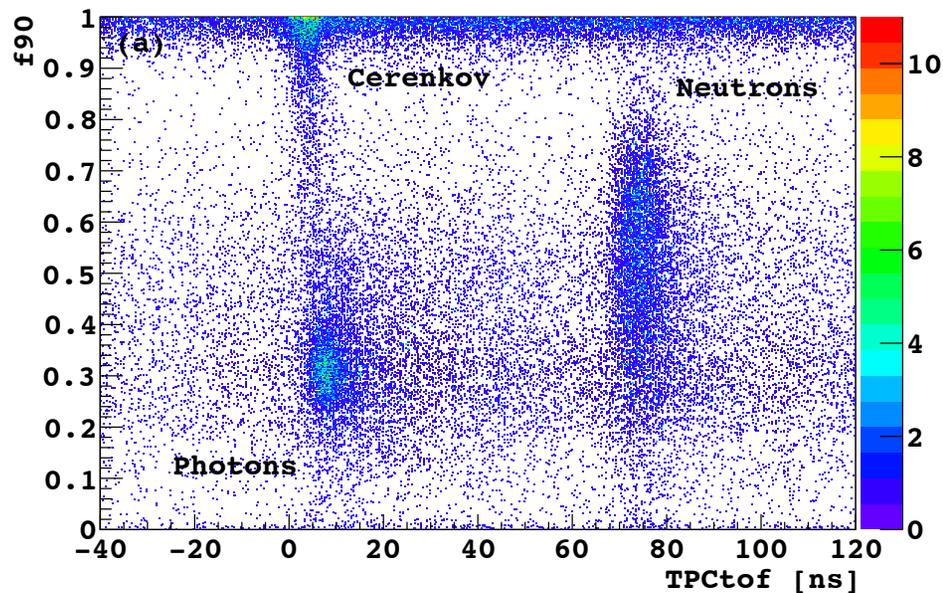
TPCtof: time difference between the proton-beam-on-target and the TPC signal

Ntof: time difference between the proton-beam-on-target and the neutron detector signal

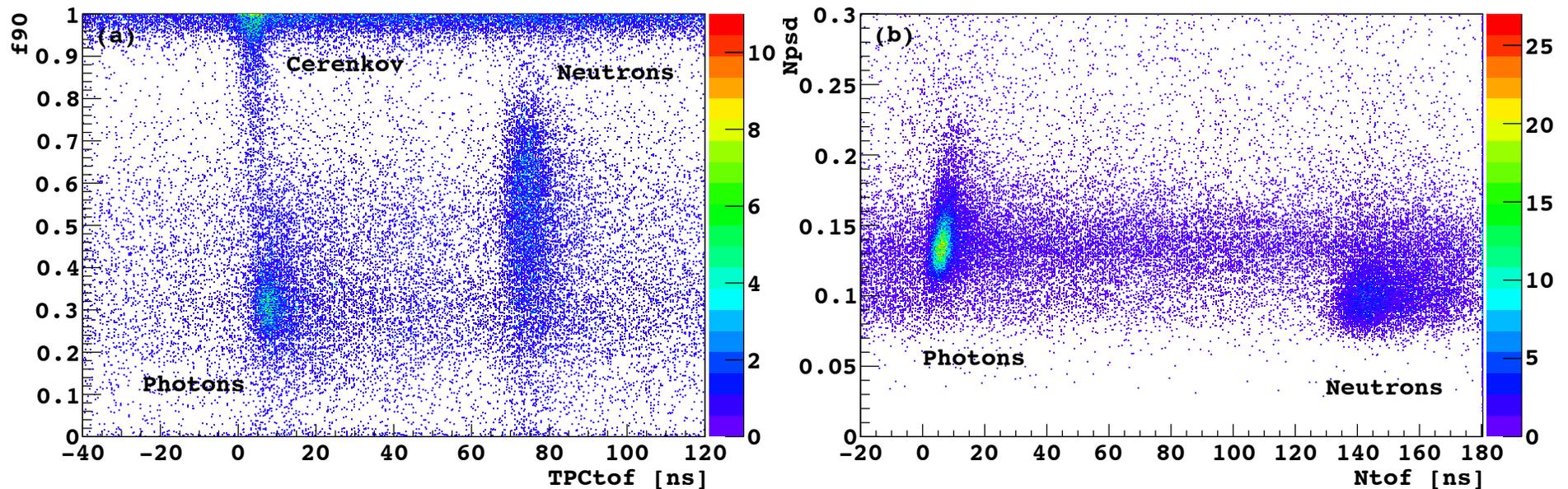
F90: PSD parameter in LAr the fraction of light detected in the first 90 ns of an event

Npsd: peak over area in the neutron detector

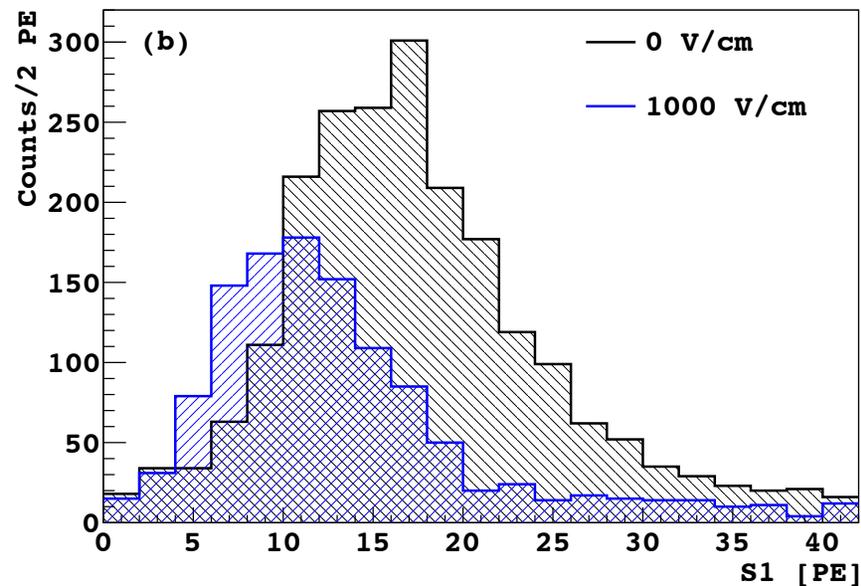
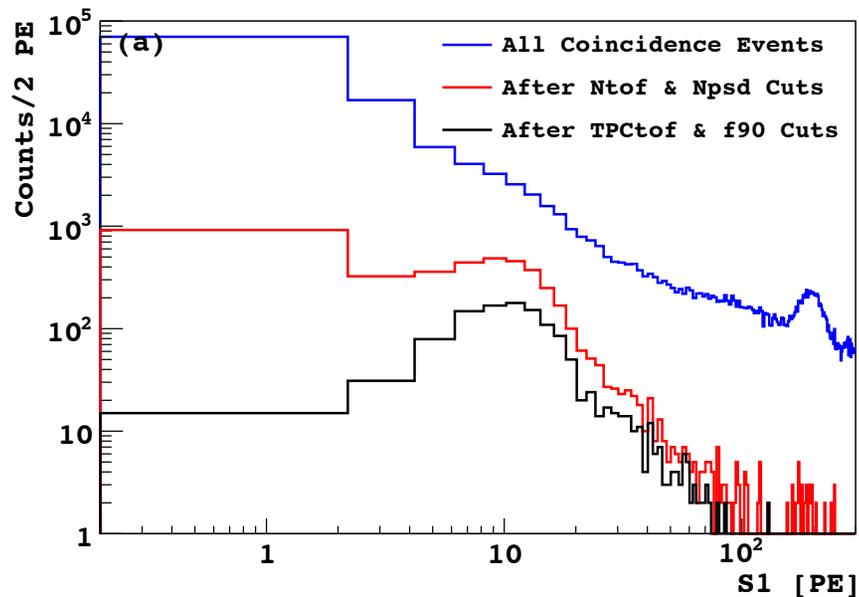
**LAr-TPC**



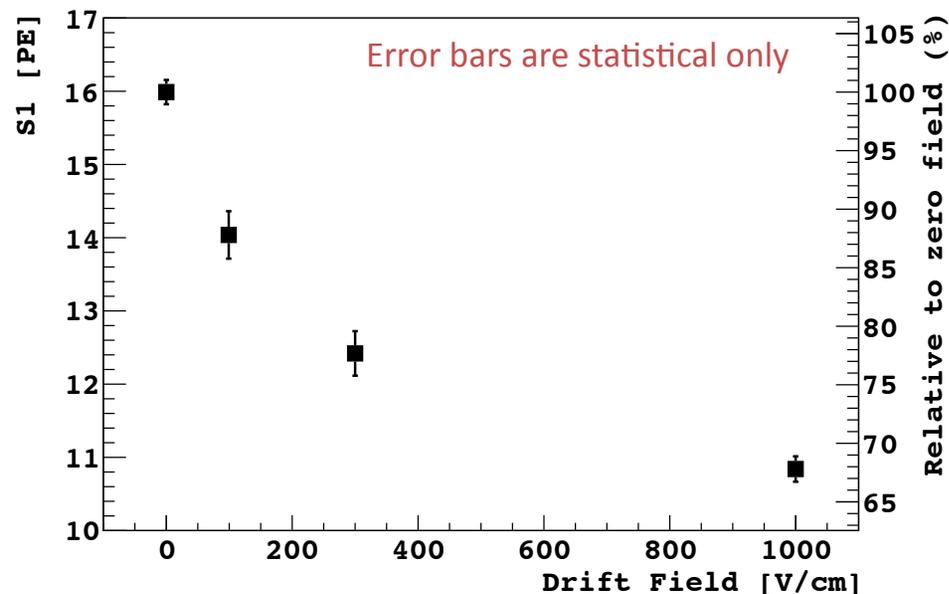
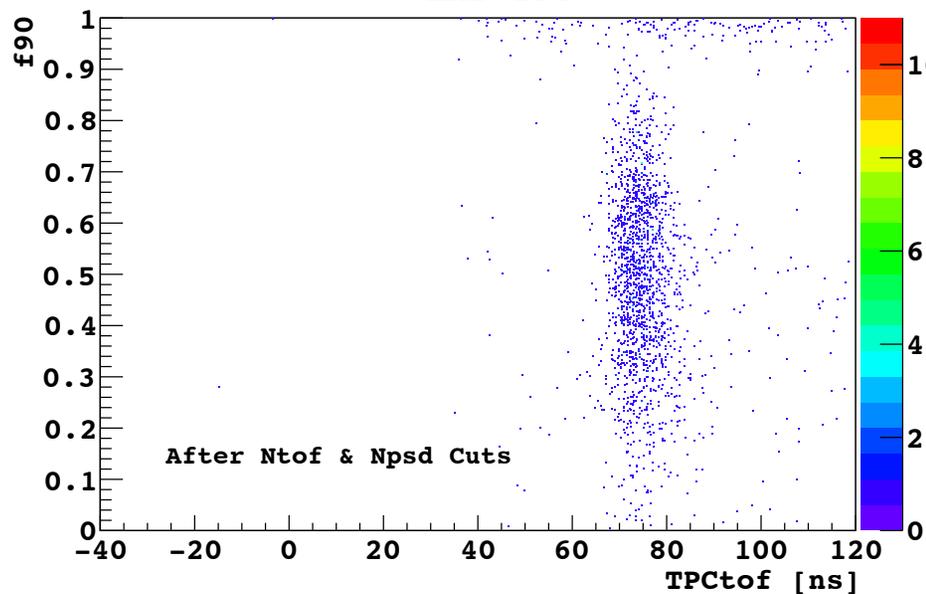
**Neutron Detector**



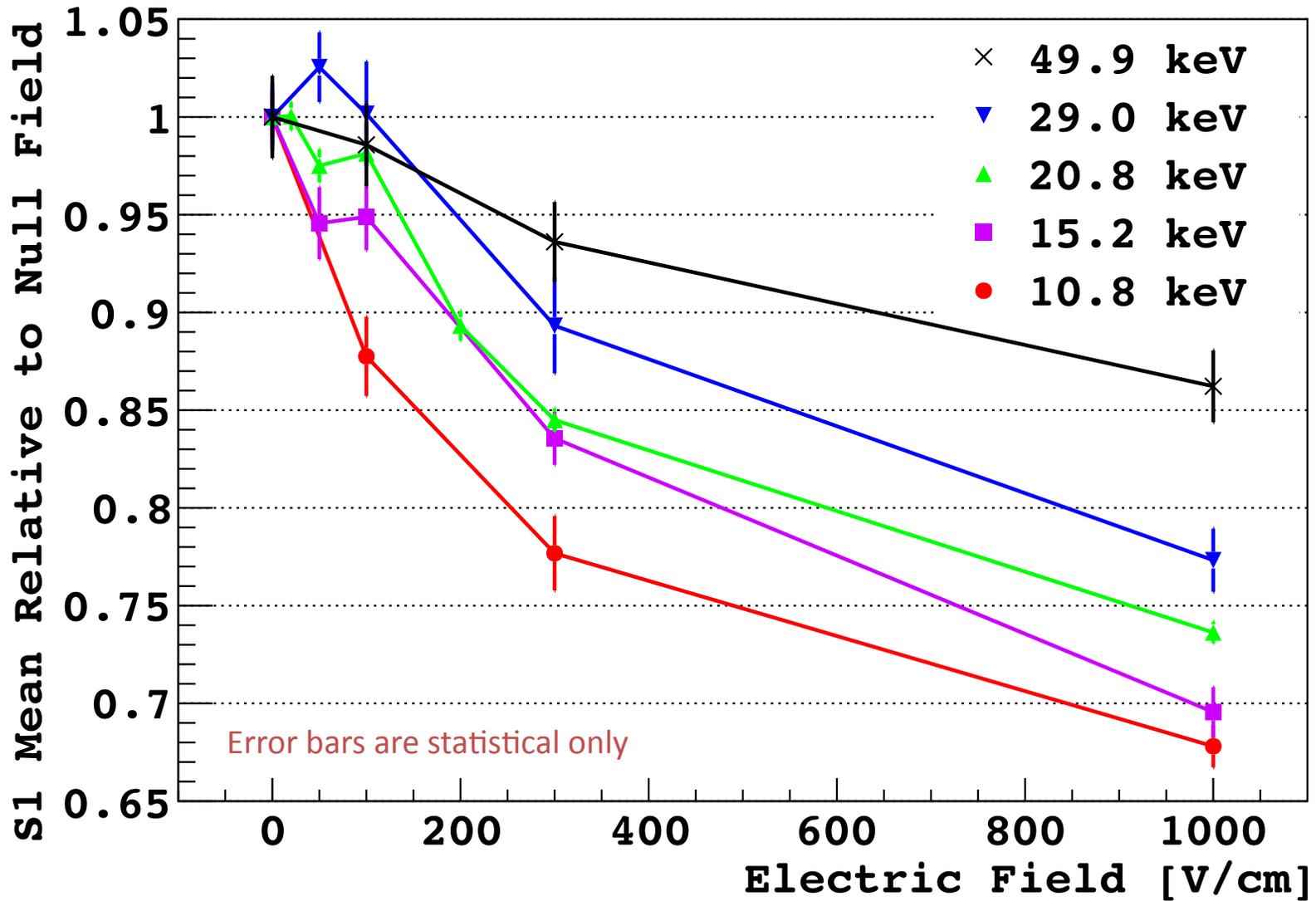
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## LAr-TPC

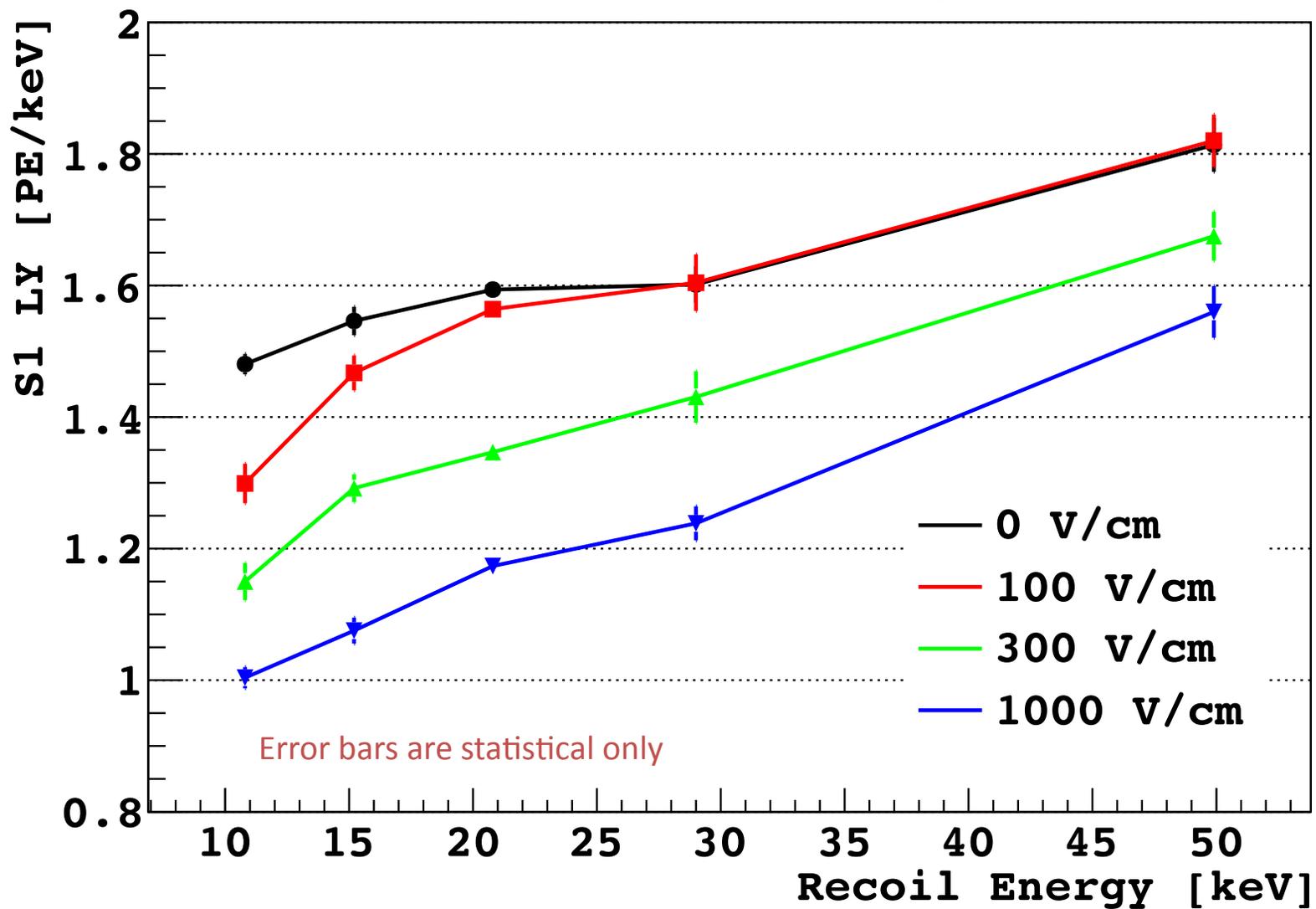


# Scintillation yield as a function of applied field



Error bars are statistical only

## Nuclear Recoil S1 Light Yield



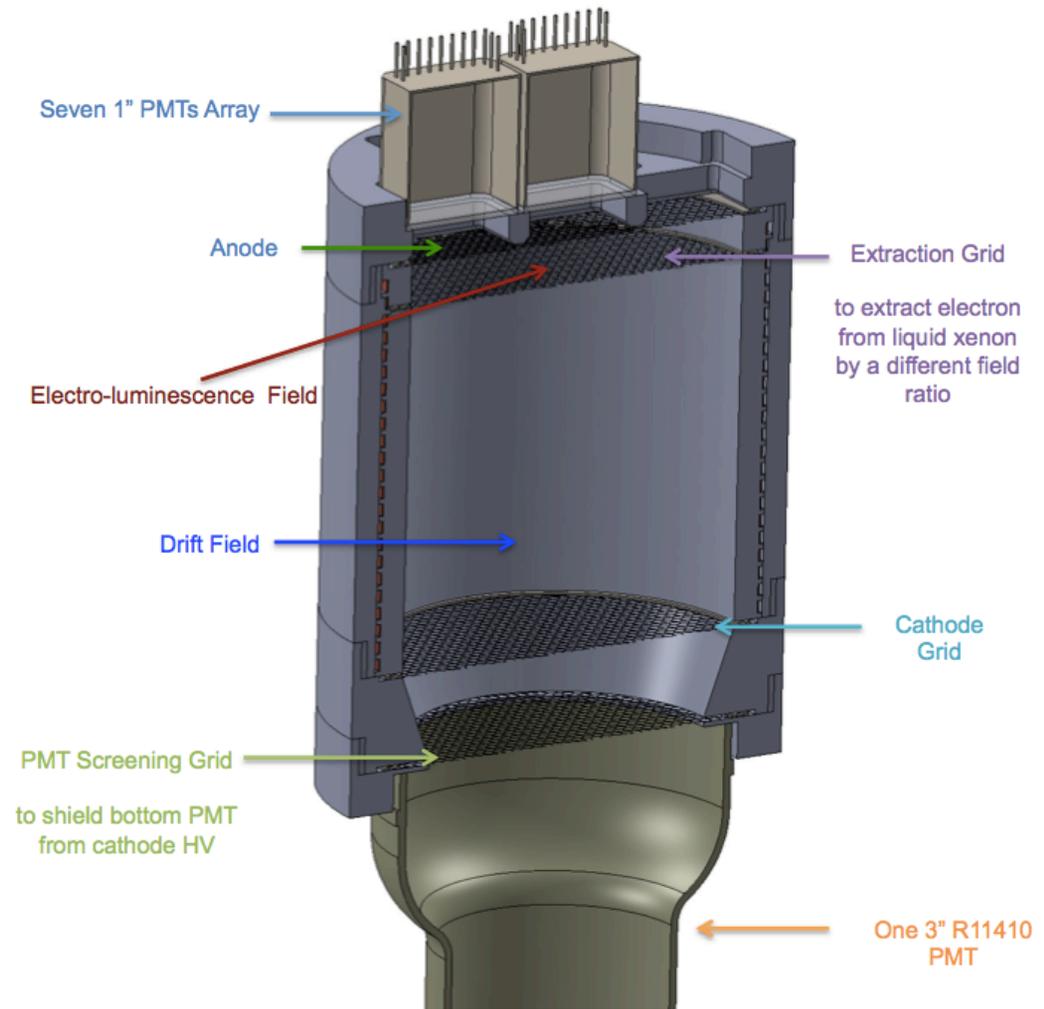
## Future Plans

On existing data

- Complete scintillation yield measurement:  
Fit data to MC spectra
- Complete S1 PSD study

Future runs

- Characterize LAr ionization from nuclear recoils
- Liquid Xe



Y. Meng 2013, UCLA